# REPORT No. 694

## THE APPLICATION OF BASIC DATA ON PLANING SURFACES TO THE DESIGN OF FLYING-BOAT HULLS

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### SUMMARY

*Basic lift data on planing surfaces have been analyzed and the data applied to the design of flying-boat hulls. It is shown that a balance between air and water forces requires that the beam of the planing area bear a relation to the wing area that is determined by the lift coefficient of the wing and by the angle of dead rise in the planing surface. It is also shown that the fore-and-aft extent of the required planing area depends on the angle of dead rise. Failure to provide sufficient length of planing area appears to be the main reason for the poor water performance sometimes obtained when a large angle of dead rise is used.*

### INTRODUCTION

In the design of a flying-boat hull to fit a given set of conditions, the selection of the proper beam is of paramount importance. Most of the methods used in the past have been based on a consideration of resistance, either directly or indirectly. It has generally been assumed that, for a given set of lines, the beam giving the best compromise between minimum take-off time and minimum air drag represents the desired solution. This assumption may or may not be true, however, depending on hull characteristics other than resistance. The most important of the characteristics in question are draft, trim, spray, and planing action. At present, it is not practicable to treat all these characteristics in a general analysis, and the only satisfactory method is to depend on model tests. These model tests assume that the basic conditions have been met, and it becomes highly desirable to separate and study the effect of each of the factors so that the initial model tests are not wasted on unsuitable lines.

Although it is impracticable, if not actually impossible, to cover the effects of draft, trim, and spray in an adequate manner, the case is quite different with respect to planing action. This action is a dynamic effect that may be considered quite apart from the remaining factors. It is merely a function of dead rise and wetted area, or wetted length. Since dead rise must, in general, be some function of the stalling speed, or the get-away speed, in order to control shock loads, it follows that a consideration of basic planing action should enter into the preliminary design. Otherwise expressed, the logical steps in design are, first, the selection of an appropriate dead-rise angle and, second, the selection of the planing area that gives normal dynamic action with this dead rise. This report is concerned with the presentation of planing data in a form that facilitates direct application to the initial stages of design.

### EFFECT OF DYNAMIC LIFT ON BEAM REQUIRED

In the planing condition, the dynamic lift developed by a flying-boat hull may be expressed in the usual coefficient form

$$L = C_{L_P}\, q\, S \tag{1}$$

where $q$ is the dynamic pressure based on water density, and $S$ is an appropriate planing area. The area selected may be either the actual area or a nominal area. Owing to the difficulty encountered in specifying or determining the actual area, it is desirable to use one of the two nominal areas available. The product of the wetted length by the beam has the apparent advantage of approximating the true area but this approximation is so poor at high trim angles with large angle of dead rise, that it is better to use the beam squared as the nominal area. The dynamic lift may therefore be given in the form.

$$L = C_{L_P}\, \tfrac{1}{2}\, \rho_w V^2 b^2 \tag{2}$$

where $\rho_w$ mass density of water.
$V$ planing speed.
$b$ beam.
$C_{L_P}$ planing lift coefficient.

For comparable water performance, the dynamic lift on the hull must bear some definite relation to the wing lift. It seems logical to assume that the dynamic lift on the hull should be equal to the gross weight of the airplane under some appropriate set of conditions that include planing speed and planing area. Since the wing lift can be equal to the gross weight at stalling speed, one comparable condition is that the hull be able to support the gross weight by dynamic reaction

when planing at stalling speed. This planing action would normally occur at the "best trim angle" and require a reasonable wetted area. From observation of high-speed planing action, it appears that the wetted length should be approximately equal to the beam. It will, therefore, be assumed that the dynamic lift is to be based on a wetted length equal to the beam.

It should be noted that the dynamic lifting capacity of a given hull is determined by planing speed, planing angle, and wetted length. In order that the lifting capacity of the hull may be related to the lifting capacity of the wings, it is necessary to make the planing speed some direct function of the stalling speed; but this condition is the only restriction on the conditions to be selected. One particular set of conditions has been selected as the most convenient and the most logical choice but any other set of conditions could be used almost as well and the only differences would be the ones associated with the introduction of different coefficients.

Solution of equation (2) gives for the required beam

$$b=\sqrt{\frac{2W}{C_{L_p}\rho_w V_s^2}} \tag{3}$$

It is less confusing, however, to obtain the solution in terms of wing lift coefficient and wing area. At stalling speed

$$L=W=C_{L_{max}}\tfrac{1}{2}\rho S V_s^2 \tag{4}$$

Combining equations (2) and (4) gives

$$C_{L_p}\tfrac{1}{2}\rho_w V_s^2 b^2=C_{L_{max}}\tfrac{1}{2}\rho S V_s^2$$

from which the required beam is

$$b=\sqrt{\frac{C_{L_{max}}}{C_{L_p}}\frac{\rho S}{\rho_w}} \tag{5}$$

Since $\rho_w=\frac{64}{32.174}=1.9892$ and $\rho=0.002378$, the ratio of densities is

$$\frac{\rho_w}{\rho}=\frac{1.9892}{0.002378}=836.5$$

Hence equation (5) may be written as

$$b=\sqrt{\frac{C_{L_{max}}}{C_{L_p}}\frac{S}{836.5}} \tag{6}$$

When $C_{L_{max}}$ and $C_{L_p}$ are constant, equations (5) and (6) require that the beam be proportional to the square root of the wing area, which is the condition for geometrical similarity. It therefore follows that a hull correctly proportioned for a given wing area and gross weight should also be correctly proportioned at any other gross weight. Experience indicates that this result is true within the limits imposed by specific characteristics of the hull. The maximum gross load is normally limited either by excessive draft and spray or by an excessive trim that upsets the dynamic balance. Some effects of these factors are discussed in reference 1.

In order to make a practical application of equation (6), it is necessary to derive values of $C_{L_p}$ in terms of the design parameters. Fortunately, the only parameters that need be considered are beam, wetted length, and angle of dead rise. Data covering the action of planing surfaces are given in references 2 and 3. These data are in reasonable agreement but, owing to the choice of presentation, the data in reference 2 are more suitable for the present study.

## EFFECT OF DEAD RISE ON HYDROPLANE LIFT COEFFICIENTS

The data in reference 2 have been converted to lift coefficient form. The procedure employed is illustrated

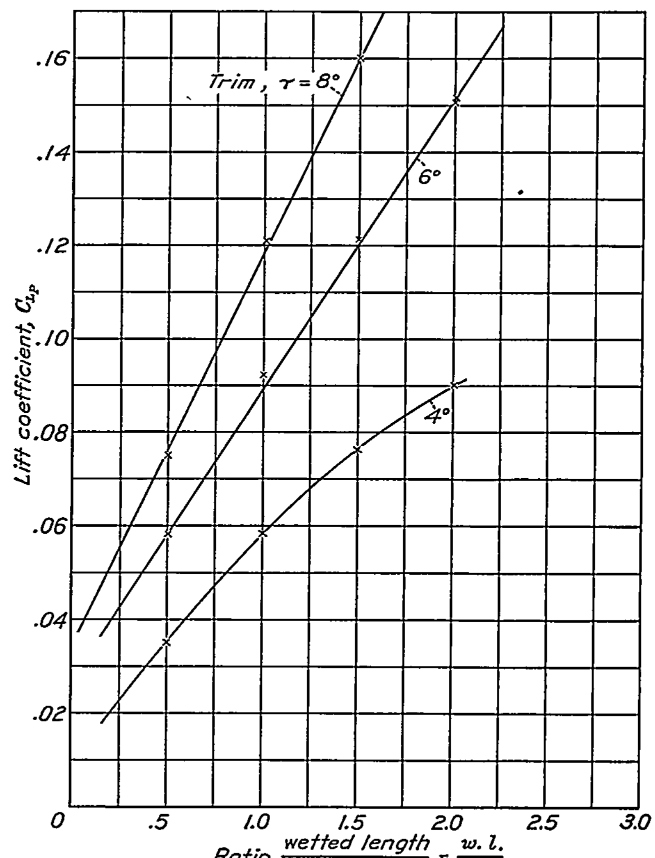


FIGURE 1.—Hydroplane lift coefficient. Angle of dead rise=0°. $L=C_{L_p}qb^2$.

by table I, which is based on figure 5 of reference 2. The speeds at which a given load is carried on each wetted length is read from the original curves. This speed is then used in equation (2) to determine the value of $C_{L_p}$. A set of calculations similar to those in table I were made for each angle of dead rise and each trim angle. The resulting lift coefficients are plotted on figures 1 to 4.

Since the comparison is to be made on the basis of constant wetted length, a cross plot of the values of $C_{L_p}$ at $w.\ l.=b$ from figures 1 to 4 is given in figure 5.

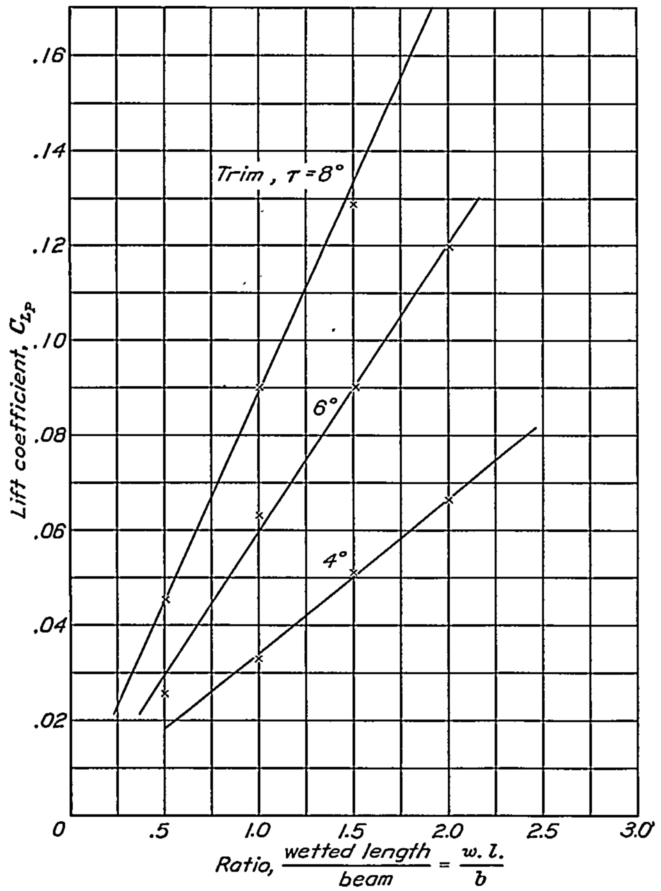


FIGURE 2.—Hydroplane lift coefficient. Angle of dead rise=10°. $L=C_{L_p}qb^2$

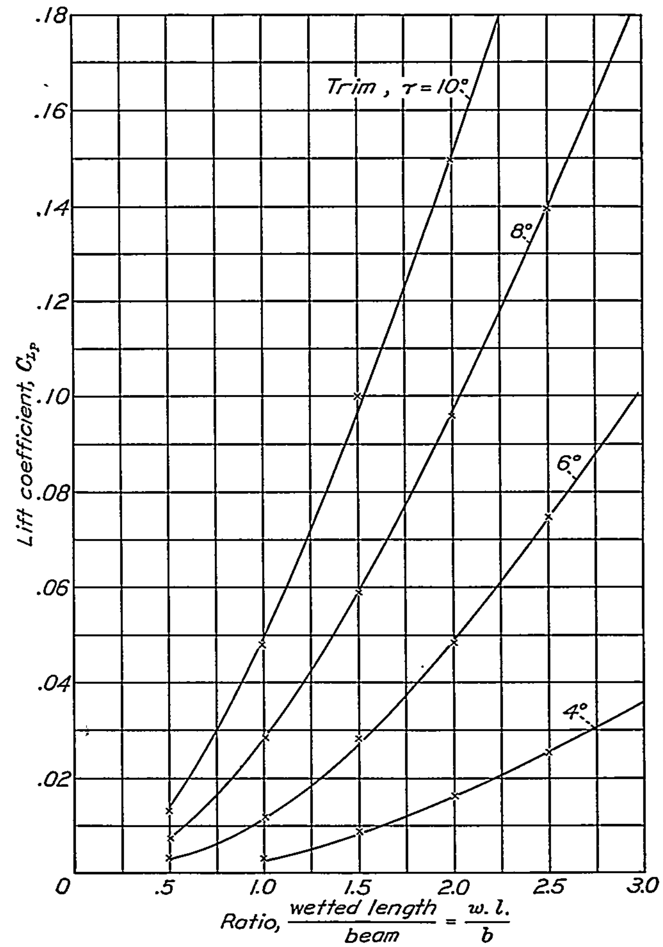


FIGURE 4.—Hydroplane lift coefficient. Angle of dead rise=30°. $L=C_{L_p}qb^2$.

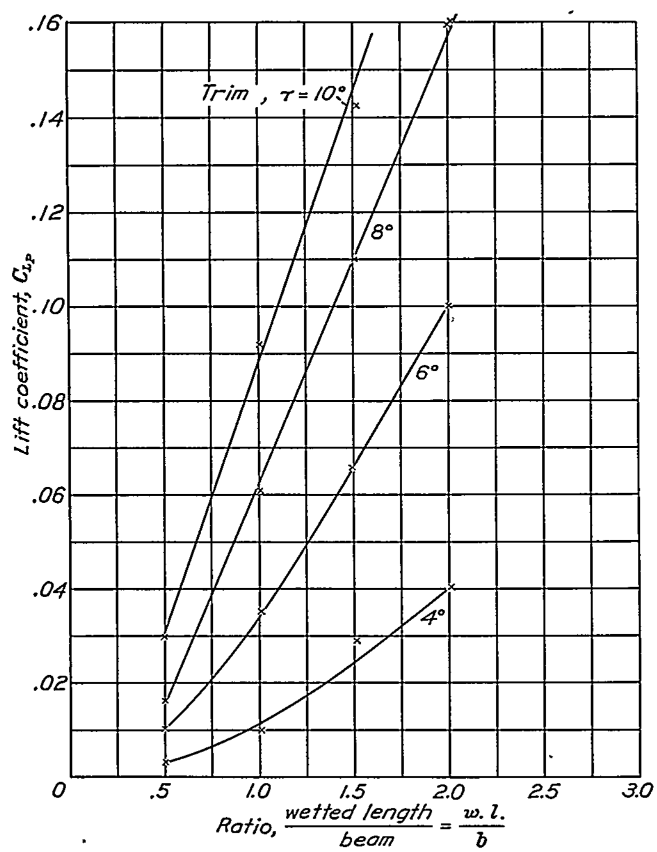


FIGURE 3.—Hydroplane lift coefficient. Angle of dead rise=20°. $L=C_{L_p}qb^2$.

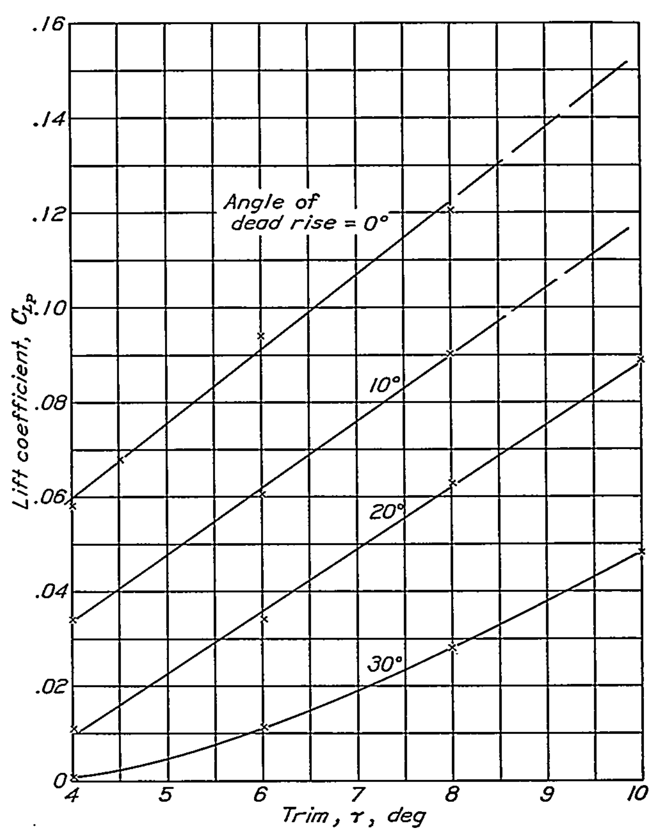


FIGURE 5.—Hydroplane lift coefficient for wetted length=beam. $L=C_{L_p}qb^2$.

### BEST TRIM

Figure 5 shows that the effect of increasing the angle of dead rise is to cause a marked reduction in $C_{L_P}$ at constant trim or to require a large increase in trim to maintain a constant value of $C_{L_P}$. Neither of these conditions, however, is a true measure of the effect sought because the planing action presumably occurs at the best trim, which is by definition the trim for minimum resistance.

Some data on the best trims are given in figures 20, 22, 24, and 26 of reference 2. These data have been supplemented by a series of new plots similar to figure 6. From these plots, the average values of best trim appear to vary with angle of dead rise as follows:

| | | | | |
|---|---|---|---|---|
| Angle of dead rise | 0° | 10° | 20° | 30° |
| Best trim | 4. 5° | 5. 0° | 6. 5° | 8. 8° |

These values are plotted on figure 7.

### PLANING LIFT COEFFICIENT AT BEST TRIM

The effect of angle of dead rise on the planing lift coefficient at best trim is obtained by reading from figure 5 the lift coefficients at the trims taken from figure 7. These values are:

| | | | | |
|---|---|---|---|---|
| Angle of dead rise | 0° | 10° | 20° | 30° |
| Best trim | 4. 5° | 5. 0° | 6. 5° | 8. 8° |
| Corresponding $C_{L_P}$ (*w. l.*=*b*) | 0. 068 | 0. 048 | 0. 041 | 0. 038 |

Figures 29 to 32 of reference 2 give curves of *w. l./b* plotted against the planing coefficient $K$, which is identical with $C_{L_P}$. Taking the intersections at *w. l./b*=1.0 gives values that are in close agreement with the present analysis, as shown by the points on figure 8. The two methods should give identical results and any lack of agreement is probably due to difficulties in plotting and reading the small scale values of $K$ from the figures in reference 2. These $K$ values would have been used directly except for the divergence noted in the data for the 30° angle of dead rise. This divergence may possibly be due to difficulty in determining best trims. The point in question is of some importance and may require additional tests with a 40° angle of dead rise in order to obtain the desirable accuracy in this range.

### APPLICATION OF PLANNING DATA TO DESIGN

Equation (6) may be written in the form

$$b=K\sqrt{S} \tag{7}$$

where

$$K=\sqrt{\frac{C_{L_{max}}}{836.5\ C_{L_P}}} \tag{8}$$

For any assumed value of $C_{L_{max}}$, the coefficient $K$ is a function of $C_{L_P}$, which in turn depends only on the angle of dead rise. It is therefore possible to give $K$ in terms of $C_{L_{max}}$ and the angle of dead rise as in figure 9. In this form the required beam is readily determined from basic design data. Figure 10, obtained by cross-plotting the curve of figure 9, is in a form more convenient for general use.

Table II gives, for a number of flying boats, a comparison between the actual value of $K$ and the value determined by figure 10. The average actual value of $K$ has been approximately 10 percent greater than that given by figure 10. The consistent use of a larger beam than required on the basis of figure 10 may be due to the combined effect of several factors. First, there is no assurance that the best beam has always

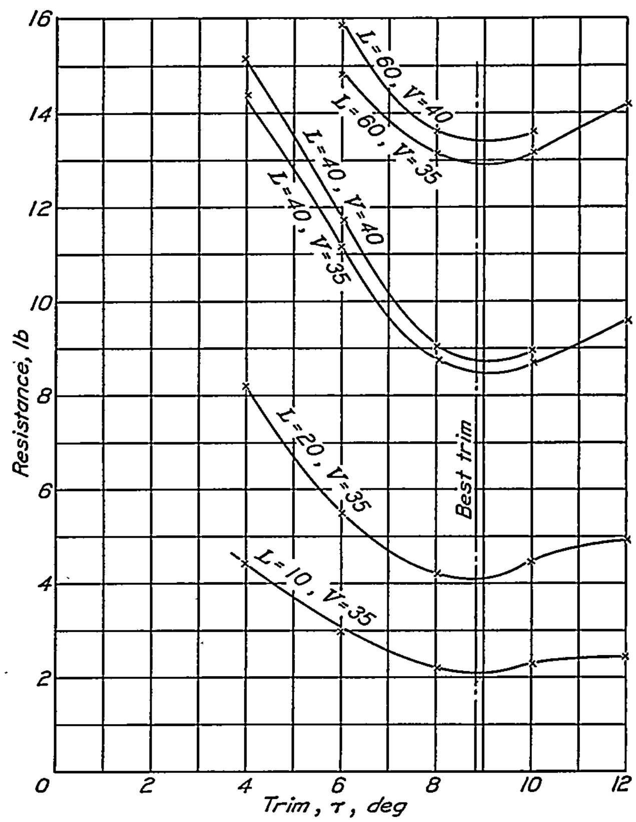


FIGURE 6.—Best trim for 30° dead rise.

been used or that the actual beam used gave the best dynamic action. Second, the assumptions on which figure 10 are based do not represent exact relations. For example, the use of 0.95 $V_s$ instead of $V_s$ as the planing speed in equation (2), at which the dynamic lift equals the gross weight, is sufficient to bring the average actual value into exact agreement with the indicated value.

In view of these considerations, it appears that the beam given by equation (7), with $K$ taken from figure 10, is of the nature of a lower limit and that a slightly larger value is indicated by the average of design practice.

### EFFECT OF DEAD RISE ON PLAN FORM OF PLANING AREA

It has been known for many years that one of the effects of dead rise is a reduction in the lift obtained in

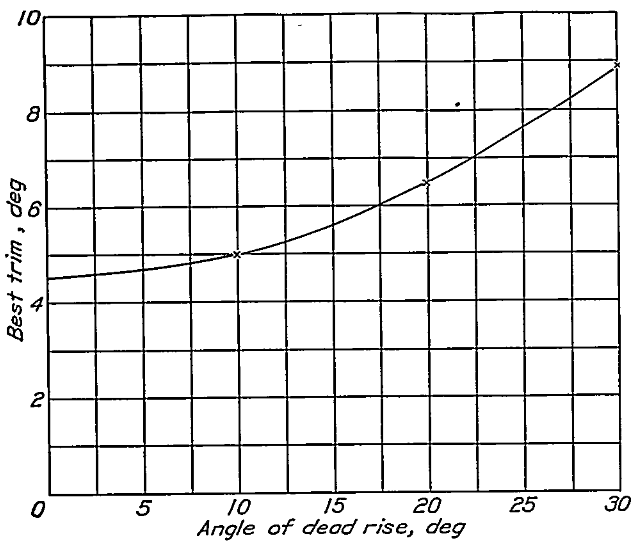


FIGURE 7.—Effect of dead rise on best trim.

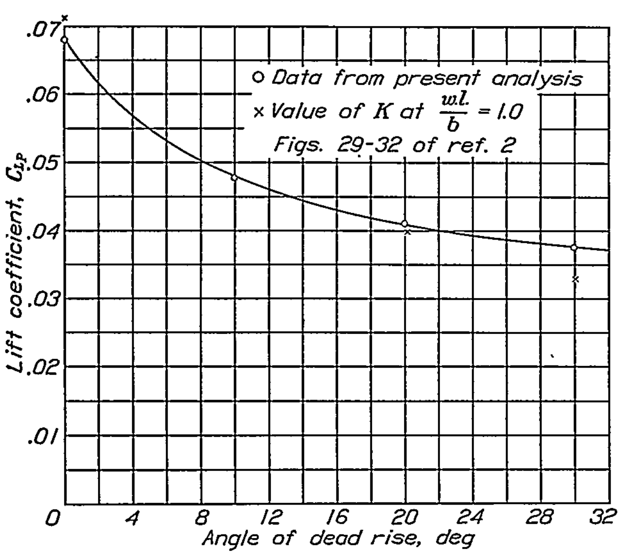


FIGURE 8.—Effect of dead rise on planning lift coefficient at best trim. Wetted length=beam. $L=C_{L_p}qb^2$.

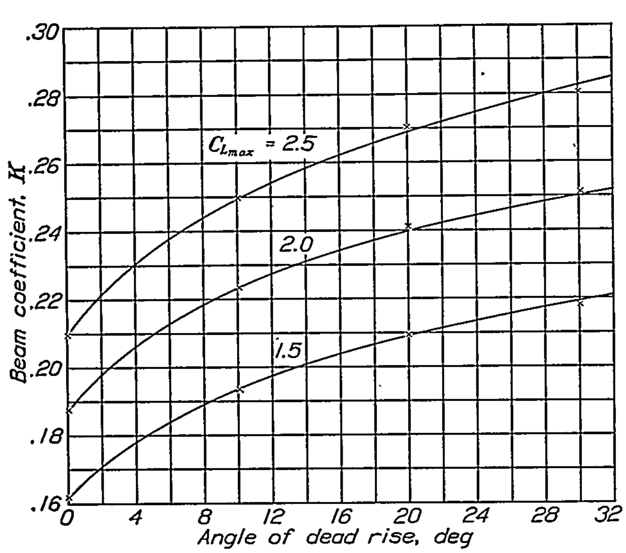


FIGURE 9.—Beam coefficient as a function of angle of dead rise and $C_{L_{max}}$.

the planing condition. In order to develop a given lift at a given speed, the larger values of dead rise require either an increase in trim angle or an increase in wetted length. The normal condition would involve an increase in both trim angle and wetted length, but the significance of the effect of dead rise is probably best shown by the increase in wetted length required to maintain a given lift coefficient at constant trim, as indicated in figure 11, which is based on the data in figures 1 to 4. The curves in figure 11 fall into groups determined by the trim angle, the curves in each group being substantially parallel. The increment in wetted length is therefore dependent only on dead rise and angle of attack, as shown on figure 12. The dotted curve on figure 12 represents the best trim condition.

There is a very practical significance in figure 12. It shows how much additional planing area is required

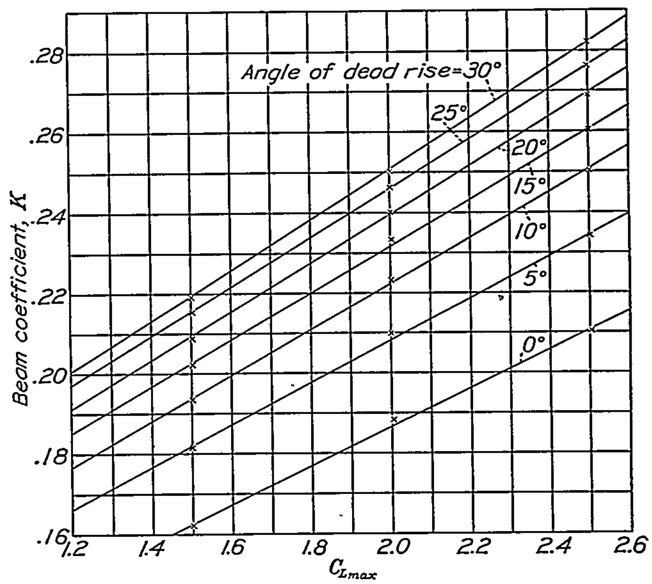


FIGURE 10.—Beam coefficient as a function of $C_{L_{max}}$ and angle of dead rise.

for an increase in dead rise. If one beam length of uniform planing bottom is sufficient for 0° angle of dead rise, then approximately two beam lengths would be required for a 25° angle of dead rise. This additional area has not always been provided in the past. It appears that the failure to provide sufficient planing area may partly explain the poor water performance often obtained when large angles of dead rise are used.

## GENERAL DISCUSSION

This study has been made with several ends in view. The chief purpose, as previously stated, was an attempt to evaluate the effects of dead rise on the hydrodynamic performance of seaplane hulls. The fact that basic data on planing surfaces could be employed for design purposes was not fully appreciated until the analysis was well under way. It now appears highly desirable that the data of reference 2 be extended to cover higher trim angles; additional loads; and, in particular, one or more values of dead rise in excess of 30°. For these higher values of dead rise the model length should be

sufficient to cover the planing range under heavy loads. The model length in reference 2 was 60 inches, or 3.75 times the model beam. It seems desirable that this length be increased to approximately six times the beam. The four models in reference 2 employed flat planing surfaces. The modern flying boat usually incorporates (for better spray control) some transverse curvature either in the form of concave sections or in the form of down flare at the chine. One effect of transverse curvature is to give high local loads, which probably results in a greater average load over the entire bottom. The investigation of planing surfaces will not be complete until the magnitude of this effect has been determined.

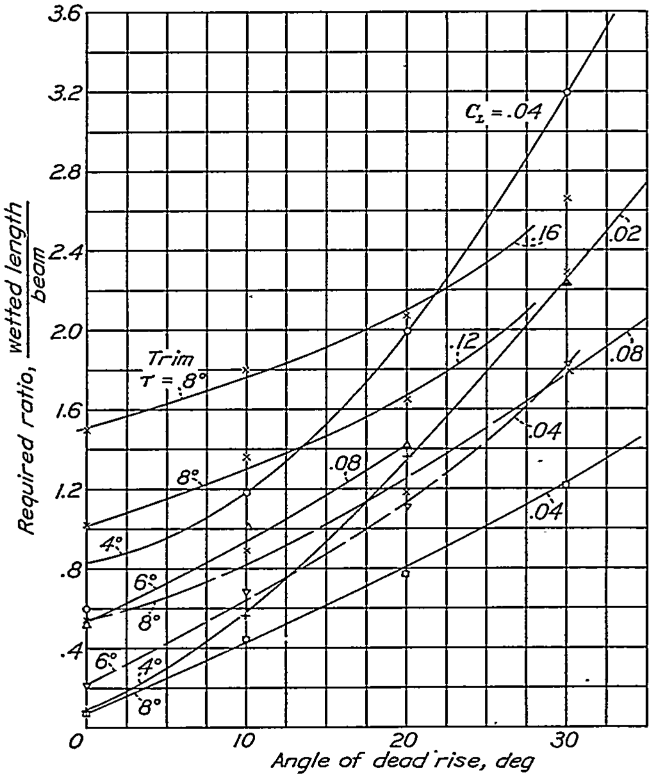


FIGURE 11.—Effect of dead rise on wetted length required to give constant lift at constant trim.

When the complete data are available, it should be possible to derive a series of charts, similar to figure 10, from which a required beam can be determined as a function of the transverse contour of the planing surface. It must be emphasized that the solution represented by figure 10 is not a final solution and the proper beam for any set of design conditions must be selected after consideration of all factors involved. These factors include air resistance, water resistance, spray control, and general seaworthiness in addition to the balance of dynamic forces that has formed the basis of this study.

## CONCLUSIONS

As a result of this study of planing action, certain conclusions may be drawn as follows:

1. It appears practicable to use basic planing data in the design of flying-boat hulls.
2. The existing data do not cover a sufficient range in form and extent of testing. Additional tests are highly desirable.
3. There is strong indication that a correct dynamic planing action of the hull is one of the chief factors in a successful design.
4. When sufficient data are available on the planing action of surfaces with various transverse sections, it should be possible to calculate the plan form of the planing area for the hull best suited to meet a given set of design conditions.
5. Large angles of dead rise require a marked increase in the fore-and-aft extent of the planing area. A poor planing action, sometimes obtained with large angles of dead rise, is probably due to failure to provide sufficient length in the planing area.

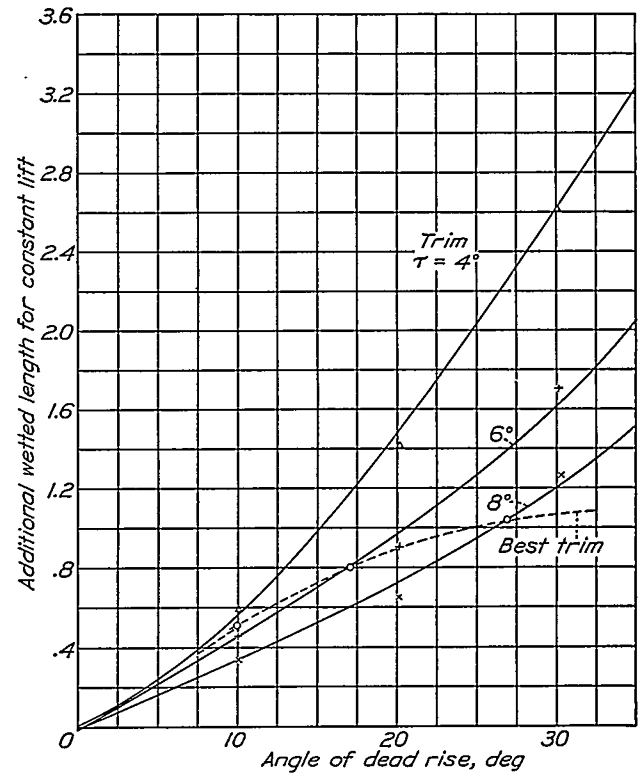


FIGURE 12.—Effect of dead rise on wetted length required to give constant lift.

BUREAU OF AERONAUTICS, NAVY DEPARTMENT,
WASHINGTON, D. C., *December 16, 1939.*

## REFERENCES


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2. Shoemaker, James M.: Tank Tests of Flat and V-Bottom Planing Surfaces. T. N. No. 509, N. A. C. A., 1934.
3. Perring, W. G. A., and Johnston, L.: The Hydrodynamic Forces and Moments on Simple Planing Surfaces, and an

Analysis of the Hydrodynamic Forces and Moments on a Flying Boat Hull. R. & M. No. 1646, British A. R. C., 1935.

## TABLE I

### HYDROPLANE LIFT COEFFICIENT

[Angle of dead rise, 0°; Trim 6°; model beam, 16 in.; water density in tank, 63.5/32.174; $L=C_{L_P}qb^2$]

| Load carried $L$ (lb) | w. l.=8 in. | | w. l.=16 in. | | w. l.=24 in. | | w. l.=32 in. | |
|---|---|---|---|---|---|---|---|---|
| | Speed $V$ (fps) | $C_{L_P}$ | $V$ | $C_{L_P}$ | $V$ | $C_{L_P}$ | $V$ | $C_{L_P}$ |
| 20 | 14.2 | 0.057 | (11.0) | (0.094) | | | | |
| 40 | 19.5 | .060 | 16.2 | .087 | 14.0 | 0.117 | (10.3) | (0.150) |
| 60 | 24.0 | .059 | 19.3 | .093 | 17.0 | .120 | 15.0 | .152 |
| 80 | 28.5 | .057 | 22.0 | .094 | 19.5 | .126 | 17.6 | .150 |
| Average | | .058 | | .092 | | .121 | | .151 |

## TABLE II

### COMPARISON OF ACTUAL BEAM COEFFICIENTS FOR REPRESENTATIVE FLYING BOATS WITH VALUES INDICATED BY FIGURE 10

| Airplane | Wing area $S$ (sq ft) | Beam $b$ (ft) | Angle of dead rise (deg) | Probable $C_{L_{max}}$ | Beam coefficient | | |
|---|---|---|---|---|---|---|---|
| | | | | | Actual $A$ | From fig. 10 $B$ | Ratio $\frac{A}{B}$ |
| NC | 2,380 | 10.0 | 22.5 | 1.2 | 0.205 | 0.195 | 1.05 |
| PB-1 | 1,801 | 9.33 | 22.5 | 1.4 | .220 | .205 | 1.08 |
| PH-1 | 1,180 | 8.34 | 22.5 | 1.4 | .243 | .205 | 1.18 |
| P2H-1 | 2,742 | 11.5 | 22.5 | 1.4 | .220 | .207 | 1.06 |
| P2M-1 | 1,204 | 8.67 | 25.0 | 1.4 | .250 | .210 | 1.19 |
| P2Y-1 | 1,110 | 8.41 | 22.5 | 1.4 | .254 | .205 | 1.24 |
| PBY-1 | 1,400 | 10.0 | 22.5 | 1.5 | .267 | .213 | 1.25 |
| P3D-2 | 1,245 | 8.33 | 20.0 | 1.8 | .236 | .228 | 1.04 |
| PBS-1 | 1,670 | 10.0 | 19.4 | 2.0 | .245 | .240 | 1.02 |